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From Stardust to Us: New Insight into Nuclear Synthesis from Heavy Stars, Supernova, Collapsars, and Gamma-Ray Bursts

Rob Hoffman

Most of the elements we encounter in everyday life were formed in the cores of massive stars, which end their lives in spectacular deaths heralded by a supernova explosion. These stars die because the conversion from mass to energy predicted by Einstein becomes inefficient as the star forms successively heavier elements. Ultimately the star collapses under its own gravity, a supernova is born, and newly formed heavy elements are expelled into the galaxy. These nuclear ashes eventually become our sun, our planet, and our bodies. We illustrate recent work on the synthesis of elements by stars that die in different ways and show that some elements—including zinc, copper and silver—may have their origins in stars so massive they collapse to form black holes. If so, the raw material for the pennies in our pockets is directly associated with the event horizons first predicted by Einstein's theory of gravity.

Perspectives on Gamma-Ray Bursts

Jay D. Salmonson

Gamma-ray bursts are touted to be the most powerful explosions in the known universe since the Big Bang. These distant, mysterious flashes of high-energy radiation have recently been discovered to be the last gasp in a fiery, explosive death of a distant star. But how and why such rare and powerful explosions take place is still unknown. This poster presents numerical simulations of possible gamma-ray-burst relativistic jet morphologies that address the question of the size and shape of the gamma-ray burst and its afterglow. By improving our understanding of what gamma-ray bursts look like, we will be better able to address the questions of how they work.

Characterization of Interplanetary Dust Particles by NanoSIMS and Transmission Electron Microscopy

Ian Hutcheon

Using nanoSIMS and transmission electron microscopy, we detected a 2175-Å absorption feature in 100-nm-size interstellar grains contained within carbon-rich interplanetary dust particles. The interstellar grains were identified on the basis of their nonsolar isotopic compositions. Although the 2175-Å extinction feature has been known as a spectral signature of dust in the interstellar medium for over 40 years, this discovery marks the first identification of actual carrier phases.

MACHO

Kem Cook

In the last decade, a number of projects have been mounted to detect and follow the progress of gravitational microlensing by compact objects, an extremely rare event. One of the original projects was the Massively Compact Halo Objects (MACHO) Project, a survey to determine whether the dark matter in the halo of the Milky Way has a significant baryonic component. The MACHO Project collected 8 years and 7.3 Tbyte of data on 99 square degrees toward the Magellanic Clouds and the bulge of the Milky Way. Half-square-degree fields were sampled, simultaneously in two bands, roughly every 3 days, and light curves for about 55 million stars to a depth of about magnitude 21 have been collected in a photometry database. This database has been analyzed for microlensing, and about 500 events toward the Bulge and about two dozen toward the Magellanic Clouds have been detected. Our analyses of these data have shown that microlensing has been detected, and all of the predicted variations due to the breakdown of the standard simplifying assumptions of point source, point lens, and uniform motion have been identified. Microlensing has been used to detect compact baryonic dark matter, to study stellar atmospheres at a level of detail impossible without microlensing, and to detect extra-solar planets.

Peering at the Origin of the Universe, Looking Deep without Blinking: LSST Survey of Dark Matter and Dark Energy

Les Rosenberg

Based on Einstein's theoretical work, we know that the future of the Universe, whether it continues to expand forever or eventually contracts in a Big Crunch, depends on how much matter and energy it contains. The landmark observational work of Edwin Hubble in the 1920s profoundly changed our picture of cosmology by establishing that the Universe was indeed expanding. Two other discoveries in the 20th century contributed to the question of the fate of the Universe. Beginning in the 1930s, it became increasingly clear that galaxies, clusters of galaxies, and all large structures contained huge amounts of some new kind of matter, called "dark matter," which greatly outweighed the ordinary stuff of stars. Second, in the late 1990s, it was discovered that the expansion of the Universe is not slowing down but accelerating, implying the existence of a mysterious repulsive force, called "dark energy," whose energy density greatly exceeds even that of dark matter. We know neither what the dark matter or dark energy is. To illuminate these questions, LLNL is helping build the 8.4-m-diameter Large Synoptic Survey Telescope, which will look back in time at the distributions of dark matter and dark energy in the Universe. By looking for the subtle bending of light caused by dark matter, we can create a map of the distribution and evolution of dark matter going back billions of years. By carefully mapping out the red shift vs. distance for various objects, we can also map out the distribution of dark energy to enormous distances, and thereby constrain various theories for what dark energy might be.

Searching for Dark Matter Close to Home: Axion Dark Matter Experiment

Les Rosenberg

The amount of matter in the Universe has been of great interest to scientists since the time of Einstein. Dynamic observations of galaxies, clusters of galaxies and other large-scale structures in the Universe, as well as gravitational lensing, imply there are large amounts of dark matter in the Universe, i.e. stuff other than ordinary stars, planets, and gas clouds. We do not know what the dark matter is, but one prominent idea suggests that it is made up of one or more species of particle relics from the Big Bang. In the 1970s, Frank Wilczek, one of this year's Nobel Laureates, recognized that a minimal extension of the theory of the force that holds the atomic nucleus together predicts an additional elementary particle, the axion. The axion has all the properties to be an ideal dark matter candidate, i.e., it would be long-lived, possess vanishingly small interactions other than gravity, and be copiously produced during the Big Bang. For the past decade, a team led by LLNL has been looking for the axion by its resonant conversion to microwave photons in a cavity permeated by a strong magnetic field. This experiment already has a sensitivity sufficient to detect certain models of axions, should they exist. The experiment will soon become much more sensitive by incorporating new amplifiers, called SQUIDS, whose noise is approaching the irreducible limits of quantum mechanics.

Atomic X-Ray Spectra as a Probe of Black Holes

Duane Liedahl

Perhaps the most extraordinary result of Einstein's Theory of General Relativity is the prediction of black holes. Black holes, by definition, do not radiate electromagnetic energy. However, if a sufficient source of matter exists in the vicinity of a black hole—a nearby star, for example—then the gravitational field of the hole can capture this matter, creating a disk-shaped configuration called an accretion disk. Matter gradually spirals inward through the disk, eventually reaching extreme relativistic velocities as it approaches the event horizon. The disk material heats up as it nears the event horizon, and becomes x-ray luminous. Spectroscopic measurements in the x-ray band thus provide probes of matter in the strong-field limit of gravitation.

Accreting black holes in binary systems, such as Cygnus X-1, constitute some of the brightest x-ray sources in the Galaxy. On a much larger scale, many galaxies, including our own, harbor black holes at their centers, with masses from millions to billions of solar masses, which accrete material from their local environments. Extreme examples of accretion onto supermassive black holes help to explain active galaxies and quasars, which emit thousands of times the total light of our Galaxy from a region comparable in size to our Solar System.

X-ray spectra from active galaxies obtained with the current generation of x-ray observatories reveal line emission that is modified by both special relativistic and general

relativistic effects. It seems that we are witnessing matter orbiting in an accretion disk around a supermassive black hole as it prepares to cross the event horizon. Our project involves calculations of accretion disk structure, with the aim of elucidating the radiation processes near the event horizons of black holes.

High-Energy Astrophysics and Einstein

Michael Pivovarovff

The field of x-ray astronomy owes a huge debt to Albert Einstein. From explaining the physics behind the instrumentation, to providing the framework to interpret myriad observational results, his work has been crucial for explaining the way the Universe works. His explanation of the photoelectric effect (1905) is the mechanism used to generate x rays in the laboratory that are needed to calibrate high-energy detectors and telescopes. In 1918, he recognized that the index of refraction for x rays was less than unity—a fact that leads to the total external reflection of light, the basis of all focusing x-ray mirrors.

It wasn't until the late 1960s that technology allowed the development of the first x-ray telescopes, and it took another decade before NASA launched the first dedicated x-ray astronomy telescope, appropriately renamed *Einstein*. Over its 30-month mission, *Einstein* revolutionized our understanding of the x-ray universe. Since then, other x-ray telescopes, most recently the Chandra X-ray Observatory and XMM-Newton, have continued this advance. Einstein's theory of special relativity (1905) is needed to explain x-ray emission from a variety of systems, including how compact objects expel matter along their spin axes. These jets move at velocities close to the speed of light, and understanding their formation is an active area of research. Study of the interaction between the youngest neutron stars, referred to as pulsars, and their surrounding supernova remnants provide a unique opportunity to study a wide variety of phenomena.

Looking to the future, the field of x-ray astronomy will expand to higher energies, thanks to innovative technology. LLNL has developed a new method for fabricating x-ray mirrors and will partner with several other institutions to launch NuSTAR, a path-breaking mission analogous to *Einstein* that will, for the first time, provide a detailed look into the x-ray universe above 10 keV.

The Creation of Neutron Star Atmospheres on NIF: A New Paradigm in Extreme Physics

Richard Klein

Einstein's 1905 paper on the quantification of light laid the foundation for further work on understanding radiation and its interplay with matter, further explored in his 1917 paper "On the Quantum Theory of Radiation." This paper fully characterized the particle-like properties of light. We use this theory to understand the physics present in extreme astrophysical environments such as those found in the polar atmosphere of a

neutron star, where the radiation pressure can be larger than the particle pressure. Efforts are under way to develop a scaled experiment to reproduce these aspects in the laboratory, using NIF, the world's most powerful high energy laser, in tandem with the High Energy Petawatt laser, when it becomes fully operational in several years. This research is leading the way to a new paradigm for studying the extreme physical conditions associated with compact astrophysical objects like neutron stars atmospheres and event horizons of black holes in an Earth-based laboratory.

Three-Dimensional Hydrodynamics Experiments on the National Ignition Facility

Brent Blue

The interaction of a shock wave with a density perturbation is a problem of basic scientific interest, with specific application to astrophysics and inertial confinement fusion (ICF). For instance, high-Mach-number hydrodynamic jets, which can result from a shock/perturbation interaction, are ubiquitous features in astrophysics and may result from the presence of capsule joints or cryogenic fill tubes in ICF. Although the spatial scales of these systems vary over 16 orders of magnitude from supernovae jets ($\sim 10^{10}$ m) to micrometer-scale jets inside ICF capsules, they are unified by the physics of a high-Mach-number shock interacting with a perturbation at a two-fluid interface. The behavior of 2-D supersonic jets has previously been investigated in detail and compared to simulations over a wide range of conditions. In 3D, however, there are new aspects to the behavior of supersonic jets in compressible media. For example, a 3-D density perturbation that is at an angle to an incident shock is predicted to result in an asymmetric jet that evolves perpendicular to the incident shock in the compressible limit, and a tilted jet in the incompressible limit. This poster presents the NIF commissioning activities for hydrodynamics experiments as well as the results of the first set of hydrodynamics experiments on NIF.

Water under Extreme Conditions of Planetary Interiors

Larry Fried

In a combined experimental and theoretical effort, we have determined the transition from molecular to nonmolecular water (the so-called superionic phase) under extreme pressures and temperatures like those found in planetary interiors. Raman spectroscopic experiments were performed in a laser-heated diamond anvil cell. The experiments found the loss of the OH stretch, indicative of a nonmolecular materials. The experimental phase boundary is in close agreement with theory, which indicates that the experimentally observed phase is a superionic (fast proton) conductor.

LLNL Envoy to the Planet Mercury

Monika Witte

The gamma-ray spectrometer (GRS), designed and built by a multilaboratory West Coast collaboration led by LLNL, is one of seven instruments aboard the NASA Messenger spacecraft on its mission to Mercury. The GRS will be used to help determine the abundance of elements in Mercury's crust. At the heart of the GRS is a germanium spectrometer that detects gamma rays coming from Mercury's surface. The detector is made up of a germanium crystal that is cryogenically cooled and encapsulated in a gold-plated container with a nitrogen gas atmosphere. Because of its high-energy resolution, the GRS is sensitive enough to acquire very precise information from the planet's surface while it remains in space.

In its most rudimentary form the GRS is a demonstration of Einstein's photoelectric effect: gamma rays of different energy levels from Mercury interact in the germanium, electron hole pairs are freed, and their motion creates image charge, thus forming the basis for the measurement of the energy levels in the elements on Mercury's crust. Because the detector needs to operate at a very cold temperature (approximately 87 K) while Messenger is so close to the Sun, the design of the thermal insulation to protect the detector was critical. Engineers from Lawrence Livermore and Lawrence Berkeley National Laboratories developed a design with three thermal shields and a cage held in place by Kevlar twine, thus supporting the detector during launch loads and providing thermal insulation during operation.

Slip-Rate Measurements on the Karakorum Fault in Tibet May Imply Secular Variations in Fault Motion

Rick Ryerson

Beryllium-10 surface exposure dating of offset moraines on one branch of the Karakorum Fault west of the Gar basin in Tibet yields a long-term (140- to 20-thousand-year) right-lateral slip rate of $\sim 10.7 \pm 0.7$ mm per year. This rate is 10 times larger than that inferred from recent InSAR analyses ($\sim 1 \pm 3$ mm per year) that span ~ 8 years and sample all branches of the fault. The difference in slip-rate determinations suggests that large rate fluctuations may exist over centennial or millennial time scales. Such fluctuations would be consistent with mechanical coupling between the seismogenic, brittle-creep, and ductile shear sections of faults that reach deep into the crust. This somewhat controversial work is intimately tied to the analysis of information using global positioning systems that require active corrections for relativistic effects.

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